EXPERIMENTAL ASPECTS OF SUPERSYMMETY WITH R-PARITY VIOLATING COUPLINGS AT THE e^+e^- LINEAR COLLIDER.

M. BESANÇON
DAPNIA-CEA/Saclay, bat. 141, 91191 Gif Sur Yvette, France

G. MOREAU
SPhT Saclay, bat. 774 & 772, Orme des Merisiers CEA/Saclay 91191 Gif Sur Yvette, France

A very short review on phenomenological aspects of supersymmetry with violated R-parity at $e+e-$ colliders is given. We present specific examples of a search for supersymmetric particles with violating R-parity couplings at a 500 GeV $e+e-$ linear collider. The signal extraction, and the mass measurement in the case of a pair production of the lightest neutralino, are performed with the help of Monte Carlo simulation.

1 Introduction and Phenomenology

The minimal supersymmetric standard model (MSSM) assumes the conservation of the leptonic (L) and baryonic (B) numbers or, more specifically, the conservation of a so-called ($B-L$) symmetry which can be expressed in the form of a multiplicatively conserved quantum number, namely the R-parity $R_p = (-)^{(2j+3B+L)}$, for a particle with spin j. The phenomenological consequences of the conservation of R-parity are known to be 1) the pair production of supersymmetric particle 2) the decay of a supersymmetric particle always into a standard particle and a supersymmetric particle 3) the existence of a stable Lightest Supersymmetric Particle i.e. the LSP. The MSSM superpotential can be made more general by including the violating R-parity $\not{R}_p$ terms [1]:

$$\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k \tag{1}$$

where L and E (Q and U,D) denote the left-handed component of lepton doublet and antilepton singlet (quark doublet and antiquark singlet) chiral superfields respectively. The λ_{ijk}, λ'_{ijk} and λ''_{ijk} are new Yukawa couplings, where i,j and k are family indices going from 1 to 3. The 9 λ and 27 λ' terms violate L explicitely whereas the 9 λ'' terms violates B explicitely [a].

If all these new terms are present in the lagrangian, they generate an unacceptably large amplitude for proton decay. It is therefore generally assumed that one $\not{R}_p$ coupling dominates. Constraints on the $\not{R}_p$ couplings from various experimental sources already exist [2]. One of the main phenomenological consequence of the violation of R_p is the decay of the LSP. If the lightest neutralino $\tilde{\chi}^o_1$ is the LSP, then it can decay into a pair of fermion virtual-sfermion which sfermion decays in turn via one of the above mentioned $\not{R}_p$ terms.

At e^+e^- colliders, the effect of the $\not{R}_p$ terms on the phenomenology can be classified in three parts 1) **t-channel or u-channel exchange** of a slepton via

[a] We do not discuss the possible terms $\mu_i L_j H_2$.

λ_{ijk} or a squark via λ'_{ijk} couplings giving rise to standard model fermion-pair production 2) **single production** of a neutralino (with a neutrino), a chargino (with a charged lepton) or a resonant sneutrino, all involving λ_{ijk} couplings and also single production of a squark in γe interaction involving λ'_{ijk} couplings 3) **effects in the decay** of the supersymmetric particles produced in pair in the usual way in e^+e^- interactions. These decays can be either direct or indirect i.e. first the usual supersymmetric (cascade) decay down to the LSP and then the $\not R_p$ decay of the LSP. In order to have decays inside the detector, the $\not R_p$ couplings have to be greater than $10^{-5}10^{-6}$ ($10^{-7}10^{-8}$) for gauginos (sfermions). This leads to a formidable enrichment in the diverseness of the possible experimental signatures and topologies in all searches for supersymmetric particles. Smaller $\not R_p$ couplings allow the supersymmetric particle to fly and decay outside the detector.

The present study is devoted to one example of a search for a singly produced chargino with a charged lepton and to one example of a search for pair produced LSP.

2 Search for singly produced chargino with a charged lepton

The most promising way to get a direct experimental measurement of the $\not R_p$ coupling constants is to study the production of particles involving those couplings. The reason is that the rates are then directly proportionnal to a given power of the relevant $\not R_p$ coupling constant. The λ_{ijk} couplings can enter production reactions at leptonic colliders only. We have considered the single chargino production, namely, $e^+e^- \to \tilde{\chi}_1^{\pm}\mu^{\mp}$, which occurs via the λ_{121} $\not R_p$ coupling through the exchange of either a $\tilde{\nu}_{\mu L}$ sneutrino in the s channel or a $\tilde{\nu}_{eL}$ sneutrino in the t channel. Due the simple kinematic of $2 \to 2$ *body* reaction, the kinematical limit of the muon transverse momentum, $P_t^{max}(\mu)$, which could be determined experimentally, would give either a relation between the $\tilde{\nu}_\mu$ mass and the $\tilde{\chi}_1^{\pm}$ mass, through, $P_t^{max}(\mu) = (m^2_{\tilde{\nu}_\mu} + m^2_\mu - m^2_{\tilde{\chi}_1^{\pm}})/m_{\tilde{\nu}_\mu}$, or (if the $\tilde{\nu}_{\mu L}$ is not produced on shell: $\sqrt{s} < m_{\tilde{\nu}_\mu}$ or $m_{\tilde{\nu}_\mu} < m_{\tilde{\chi}_1^{\pm}}$) directly the $\tilde{\chi}_1^{\pm}$ mass through, $P_t^{max}(\mu) = (s + m^2_\mu - m^2_{\tilde{\chi}_1^{\pm}})/\sqrt{s}$. We have assumed the LSP to be the $\tilde{\chi}_1^0$ and the dominant $\not R_p$ coupling to be λ_{121}, and we have concentrated on the chargino decay: $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 l_p \nu_p$. Since the LSP decays as, $\tilde{\chi}_1^0 \to ee\nu_\mu$ *or* $\mu e \nu_e$, we obtain a $4l + \not E$ signature. The main source of Standard Model background for the $4l + \not E$ final state, which is, $e^+e^- \to Z^0W^+W^-$, can be reduced using some typical kinematical cuts (see for exemple [3]). A non-physic background comes from the Z^0 gauge boson pair production with initial state radiation of a photon (ISR). The Z^0 exclusion cut as well as some cut on the transverse missing energy together with the beam polarization effects can greatly suppress this contribution. In the following, we show how the signal can be distinguished from the main source of supersymmetric background, namely, the LSP pair production: $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0$.

Both the signal and the SUSY background have been simulated with the SUSYGEN event generator [4]. First, we have applied some cuts on the transverse momentum distribution (more peaked than the whole momentum distribution due to the ISR) of the produced muon. Those cuts depend on the SUSY spectrum as we have

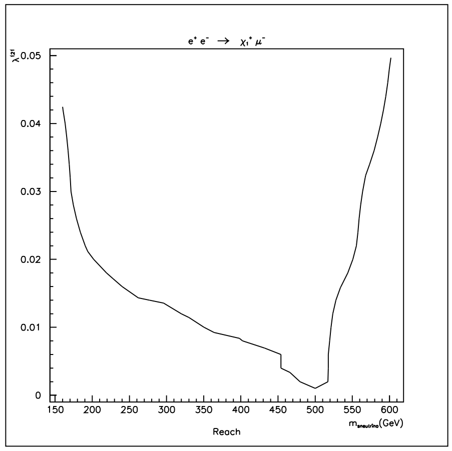

Figure 1: Exclusion plot at the 5σ level in the plane, λ_{121} versus $m_{\tilde{\nu}_\mu}$. The region above the curve is the excluded region.

described above. We have also demanded that the number of muons must be at least equal to one, which does not affect the signal. Finally, in order to take into account the observability of leptons at a Linear Collider, we have used the following cuts: $P_t(l) > 3$ GeV and $|\eta(l)| < 3$.

Neglecting the higgsino component of the gauginos, the incoming leptons in the single chargino production have the same helicity, which is not the case for the different channels of the $\tilde{\chi}_1^0$ pair production. Hence, the beam polarization effect may be used in order to enhance the signal-to-noise ratio. Furthermore, in order to reduce the SUSY background, we have selected the Left-handed electron and Left-handed positron in the initial state ($e_L^+ e_L^- \to \tilde{\chi}_1^- \mu^+$). We have assumed an electron (positron) polarization efficiency of 85% (65%) at the Linear Colliders. In Fig.(1), we present the exclusion plot at the 5σ level in the plane, λ_{121} versus $m_{\tilde{\nu}}$ at a center of mass energy of $\sqrt{s} = 500$ GeV and assuming a luminosity of 500 fb^{-1}. The chosen point of the supersymmetric parameter space is, $\tan\beta = 1.5$, M_1=150 GeV, M_2=300 GeV, $\mu = 200$ GeV, $m_{\tilde{l}_p^\pm}$=300 GeV/c^2, $m_{\tilde{q}_p}$=600 GeV/c^2. The background considered here is the $\tilde{\chi}_1^0$ pair production. At the resonance point, $m_{\tilde{\nu}} = \sqrt{s} = 500$ GeV, the sensibility on λ_{121} reaches, $\lambda_{121} < 1.15\ 10^{-4}$.

3 Search for pair produced LSP

Neutralino pairs are copiously produced at the $\sqrt{s} = 500$ GeV e^+e^- linear collider. Assuming the following points (M_2 in GeV, μ in GeV, m_o in GeV, $\tan\beta$) of the parameters space in the minimal SUGRA scheme of the package SUSYGEN[4] i.e. point I (200,320,100,3), point II (200,260160,30), point III (300,320,100,3), point IV (200,300,200,5), the mass (in GeV/c^2) and total cross-section (in pb) of pair produced neutralino $\tilde{\chi}_1^o$ i.e. the LSP are, respectively, for each point (93,0.255), (96,0.194), (141,0.158) and (94,0.166). Although the $\not{R}_p$ couplings do not intervene

in these LSP pair production, we assume one of the least constrained [2] $R\!\!\!/_p$ couplings as the dominant coupling namely, the λ''_{233} coupling which leads to a six jets signature including 2 jets from b quark.

The backgrounds from Standard Model (SM) processes are coming from 4 fermions production such as WW, ZZ, $We\nu$ and Zee as well as, to a less extent, from 2 fermions production i.e. two quarks production including top quark pair production. We have also considered backgrounds coming from other pair produced supersymmetric particles which are kinematically accessible at the $\sqrt{s} = 500$ GeV e^+e^- linear collider such as the next to lightest neutralino $\tilde{\chi}^o_2$, the lightest chargino $\tilde{\chi}^\pm_1$, the selectron $\tilde{e}$, the stau $\tilde{\tau}$ and the sneutrino $\tilde{\nu}$ (for point I and II). The LSP-signal extraction from the physical background is performed by means of Monte Carlo. The background events from SM processes have been generated with the package PYTHIA[5] and the LSP-signal events as well as the background events from other supersymmetric particles have been generated with the package SUSYGEN[4].

In order to take into account some detector effects, we have assumed a rough smearing which includes $10\%/\sqrt{E}$ electromagnetic resolution, $50\%/\sqrt{E}$ hadronic resolution, 90 % electron identification probability and 80 % efficient tagging of event with b quark with a 1 % contamination from WW events.

The LSP-signal is extracted by requiring a multiplicity of charged particle greater than 6, a total multiplicity greater than 12. The total energy and the energy of the most energetic photon are required to be respectively greater than 300 GeV and smaller than 80 GeV. Then 6 jets are requested after applying a simple cluster algorithm (luclus [5] with a maximum distance, below which two clusters can join, of 2.5 GeV) and each jet are required to be within the $[10^o, 170^o]$ polar angle interval. The b-tagging described above is applied as well as a 5-constraints kinematical fit where 4 constraints come from the 4-momentum conservation and 1 constraint comes from the requirement of the reconstruction of two objects with equal invariant mass. The difference of the two 3-jets invariant masses in the jets combination which minimizes this difference after the above kinematical fit is required to be smaller than 15 GeV and the χ^2 of the kinematical fit is required to be smaller than 90.

This selection allows a signal efficiency in the 20 % - 23 % range and a $(S/\sqrt{B})$ ratio (S for signal and B for total background) in the 8.2 - 13.6 range for the 4 points of the parameter space described above and with an integrated luminosity of 500 pb^{-1}. Looking at the 3-jets invariant mass after kinematical fit, the LSP mass can be reconstructed/measured with a precision of the order of ± 15 GeV to ± 20 GeV, see for example figure 2 for point III and IV. Furthermore this measurement is not spoiled by other supersymmetric particles.

4 Conclusion

Supersymmetry with $R\!\!\!/_p$ couplings leads to a very rich phenomenology which can be explored at the 500 GeV e^+e^- linear collider. In this study, we have presented one example of a search for a singly produced chargino with a charged lepton in which the λ_{121} $R\!\!\!/_p$ coupling can be probed at the 5σ level to a lower value than the current low energy limit [2] for a wide range of the $\tilde{\nu}$ mass and this by making

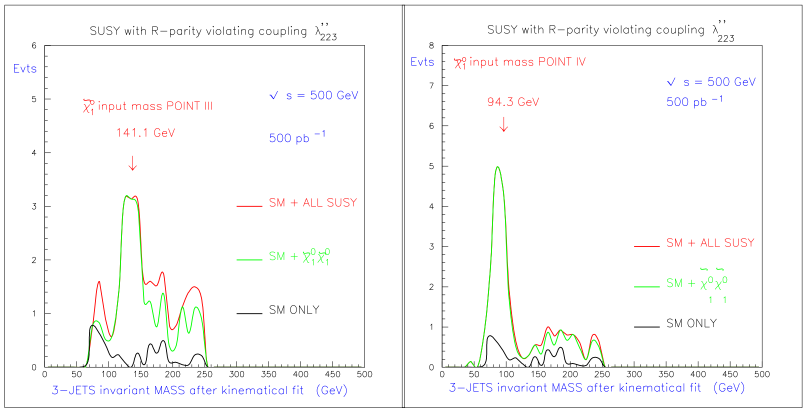

Figure 2: 3-jets invariant mass after kinematical fit for point III (left figure) and point IV (right figure).

use of the possibility of beams polarizations. We have also presented a search for the lightest neutralino pair production where the lightest neutralino decays via the λ''_{223} $\not{R}_p$ coupling leading to a 6 jets signature including 2 jets from b quark. We have shown that for various points of the MSSM parameter space, the signal can be extracted from the standard model processes as well as from the production of other supersymmetric particles, which are kinematically accessible, and the mass of the lightest neutralino can be measured. Such a signal extraction and mass measurement are made more efficient (respectively) by the use of b-tagging and by means of a simple kinematical fit.

Acknowledgments

It is a pleasure to thank H.U. Martyn and Y. Sirois for having encouraged this work.

References

1. G. Farrar and P. Fayet *Phys. Lett.* B **76**, 575 (1978), S. Dimopoulos and H. Georgi, *Nucl. Phys.* B **193**, 1981 (150), S. Weinberg, *Phys. Rev.* D **26**, 287 (1982), N. Sakai and T. Yanagida, *Nucl. Phys.* B **197**, 533 (1982), L. Hall and M. Suzuki, *Nucl. Phys.* B **231**, 1984 (419), F. Zwirner, *Phys. Lett.* B **132**, 103 (1983), R. Mohapatra, *Phys. Rev.* D **34**, 3457 (1986), R. Barbieri and A. Masiero, *Nucl. Phys.* B **267**, 679 (1986), S. Dimopoulos and L. Hall, *Phys. Lett.* B **196**, 135 (135).
2. V. Barger, G.F. Giudice and T. Han, *Phys. Rev.* D **40**, 2987 (1989), H. Dreiner, hep-ph/9707435, R. Barbier et al. hep-ph/9810232.
3. D. K. Ghosh, R. M. Godbole, S. Raychaudhuri, hep-ph/9904233.
4. S. Katsanevas and P. Morawitz, Comp. Phys. Comm. 112,(1998),227.
5. T. Sjostrand, Comp. Phys. Comm. 82 (1994) 74.